**Validity and Reliability of Valedo® System to Measure Trunk Range of Motion During Streamlined Wolf Motor Function Test in Chronic Stroke and Aged-matched Healthy Participants**

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**Abstract** (273 words)

**Background:** Upper limb impairment post stroke is often measured using clinical function tests based on ordinal scales. However, these do not consider the quality of movements such as trunk involvement during UL task performance. This study proposes using an inertial measurement system to measure trunk range of motion (ROM) during UL activity. **Objective:** This study investigates the validity and reliability of using the Valedo® system to measure trunk ROM during performance of the streamlined Wolf Motor Function Test (SWMFT). **Methods:** Forty participants (20 with chronic stroke, 20 healthy, age-matched) performed the SWMFT while wearing Valedo® sensors on their trunks to capture trunk movements. A paired sample T-test was used to examine the validity of the system in distinguishing between the healthy and stroke group, and between the affected and unaffected sides in the stroke group. Interclass correlation coefficients were used to assess the inter-rater and intra-rater reliability (between-days) with 95% CI. **Results:** The Valedo® system was able to distinguish between stroke and healthy participants; stroke participants employed greater trunk range of movements than the healthy controls in all tasks (*p*< 0.01). Furthermore, using trunk parameters recorded by the Valedo® system enabled differentiation between the affected and the unaffected hands of people within the stroke group. The reliability for the stroke group was good to excellent with intrarater reliability (ICC = 0.71–0.92) and interrater reliability (ICC = 0.63–0.95). **Conclusions:** The Valedo system demonstrates an acceptable level of validity and reliability for measuring trunk ROM during the SWMFT in research and clinical practice. Future studies with a larger sample size, different levels of UL impairment and different stages of stroke are warranted.

## Introduction

More than 62% of stroke survivors have UL motor deficits (Clery et al., 2020). Persistent UL impairment is highly prevalent after stroke, and impairments of the arm and hand are the major contributors to daily activity limitations (Bae et al., 2015). UL impairments after stroke include paresis, impaired control of voluntary movement, abnormal muscle tone and/or changes in somatosensation resulting in slow, inaccurate and uncoordinated task-related movement (Alt Murphy and Häger, 2015). These impairments can have manifold consequences in quality of life by reducing the capacity to carry out basic self-care tasks and to fulfil life-roles (e.g. domestic life, socialising and recreation) (Poltawski et al., 2016).

Compensatory movement patterns are adopted by stroke survivors during UL task accomplishment to compensate for UL motor deficits, thereby hindering the potential for motor recovery after stroke (Levin et al., 2016). Trunk compensatory movement during reaching tasks has been well recognized as a critical factor in studies of UL performance after stroke (Cirstea and Levin, 2000). Persistent usage of compensatory trunk movement strategies by stroke patients to accomplish tasks might reinforce maladaptive plasticity due to encouraging abnormal movement patterns which may affect motor recovery in the longer term (Jang, 2013). In rehabilitation intervention studies, it is critical to know the effect of the intervention on motor function, to be able to determine whether improvements in function occur due to recovery of the lost motor function or to the use of compensatory movement patterns.

Clinical function tests (e.g*.* Fugl-Meyer Assessmentfor upper limb (FMA-UL) and Wolf Motor Function Test (WMFT) are frequently used to assess UL motor recovery and function after stroke (Wolf et al., 2001, Duncan et al., 1983). However, most UL function tests mainly quantify function using ordinal scales to measure the degree of task completion or the time taken to complete the task without considering movement quality (Demers and Levin, 2017). Movement quality can be obtained by kinematic analysis of several indices (i.e., speed, smoothness and range of motion (ROM).

It is challenging to use observational clinical function tests to distinguish between true motor recovery and the use of alternative (compensatory) movement patterns during task performance (Alt Murphy et al., 2015). Therefore, it has been suggested that 3D kinematic measures should be considered to distinguish between compensation and true motor recovery (Kwakkel et al., 2017). However, motion analysis systems require a large installation space, are costly and are not readily clinically available. An alternative objective and reliable measurement system is needed to allow clinicians to assess and monitor movement dysfunction changes after stroke. Wearable sensors, such as IMUs that are easily portable, low in cost and easy to set up, might help to overcome these limitations. The Valedo® system is an IMU comprised of three lightweight sensors that measure the angular tilt and velocity of body segments with respect to magnetic ﬁelds and gravity (Bauer et al., 2015). The validity and reliability of the Valedo® system in measuring trunk movement among healthy adults (age range: 27–52) have been established by Bauer et al. (2015). The system showed sufficient psychometric properties with high validity (r2 coefﬁcients >0.94) and test inter-rater reliability (3%–9% coefﬁcient of variation). However, the validity and reliability of the Valedo® system for the stroke population during the performance of UL activities has still not been established. The aim of this studyis to investigate the validity and inter-rater and intra-rater reliability of the Valedo® system in measuring trunk movement during performance of the SWMFT by stroke survivors and age-matched healthy participants.

## Methods

### 1) Participants

A purposive sample of 20 adult chronic stroke survivors with UL impairment and 20 age-matched healthy participants was recruited from the University of Southampton - School of Health Sciences’ Research Participant Register, and local stroke clubs (Portsmouth, Romsey and Worthing). The inclusion and exclusion criteria for both groups is presented in Table 1.

Table : Inclusion and exclusion criteria for stroke and healthy participants

|  |  |  |
| --- | --- | --- |
| Inclusion criteria for stroke | Inclusion criteria for healthy | Exclusion criteria for both groups |
| * Aged 18 years or over * Able to understand the purpose of the study and follow simple instructions (assessed by telephone screening) * More than 6 months from stroke. * Able to maintain seated position * Able to lift the hand from lap to a table in front or able to move the arm sideways across a table | * Aged 18 years or over * Able to understand the purpose of the study and follow simple instructions (e.g. put hand on table and fold towel). | * History of spontaneous fractures. * Uncontrolled epileptic seizures (less of consciousness or uncontrolled rapid movements). * Acute shoulder, elbow or hand pain or problems that affect the movement of the arm. * Implanted ferromagnetic materials or active devices within the body (i.e. pacemaker, acoustic devices). * Skin disease or lesions in correspondence of: sternum, L1, S1 (i.e. Psoriasis or eczema). * Severe communication disorders - unable to follow simple instructions (i.e. to cross one leg, to clap hands, or unable to ask a simple question if needed). * Pregnancy * Complete arm paralysis |

### 2) Measurement Protocol

The WMFT has been recommended for assessing upper extremity function in research and clinical practice (Alt Murphy et al., 2015), however it is lengthy to administer and potentially might cause fatigue for stroke patients with low levels of exercise tolerance. Two streamlined versions of the WMFT (SWMFT) are recommended based on Rasch analysis, one for subacute stroke and one for chronic stroke patients (Chen et al., 2012, Bogard et al., 2009). The SWMFT has sufficient psychometric properties and a high sensitivity to change for individuals with stroke over time, based on a Rasch analysis study (Chen et al., 2012, Wu et al., 2011). Both versions include four common tasks—hand to box (Front), lift can, lift pencil and fold towel. In addition, the subacute version of SWMFT (SWMFT-S) includes hand to table (Front) and reach and retrieve tasks, while the chronic version of SWMFT (SWMFT-C) includes extend elbow (1 lb weight) and turnkey in lock (Bogard et al. 2009) tasks. All eight tasks were used in this study to provide data that could be used for a comparison with subacute stroke patients in the future.

Before starting the assessment, the participant was instructed to turn off their mobile phone to avoid interference with the Valedo® sensors. The three Valedo® sensors were placed on the participant’s trunk while standing using double-sided sticky tape. The sensors were placed as follows: sensor one on the sacral spinal level S1, sensor two on the L1 spinal level and sensor three on the sternum. The following anatomical body landmarks were used to identify the S1 and L1 levels: the anterior superior iliac spine (ASIS) along the iliac crest to L4 and from there moving upward and downward to locate L1 and S1 (Figure ‎1).

A picture containing person, swimsuit

Description automatically generated

Figure ‎1: Sensor placements

The participant was seated on a chair with back support, with 90 o knee and hip flexion, behind a height-adjustable table (Figure 2). Then, the participant was verbally instructed to perform all eight tasks from the SWMFT-S and SWMFT-C; the Valedo® sensors recorded the trunk ROM for each task onto a laptop via Bluetooth. The recorded ROM data was exported as Excel sheets and processed using the MATLAB program (MATLAB R2019a).

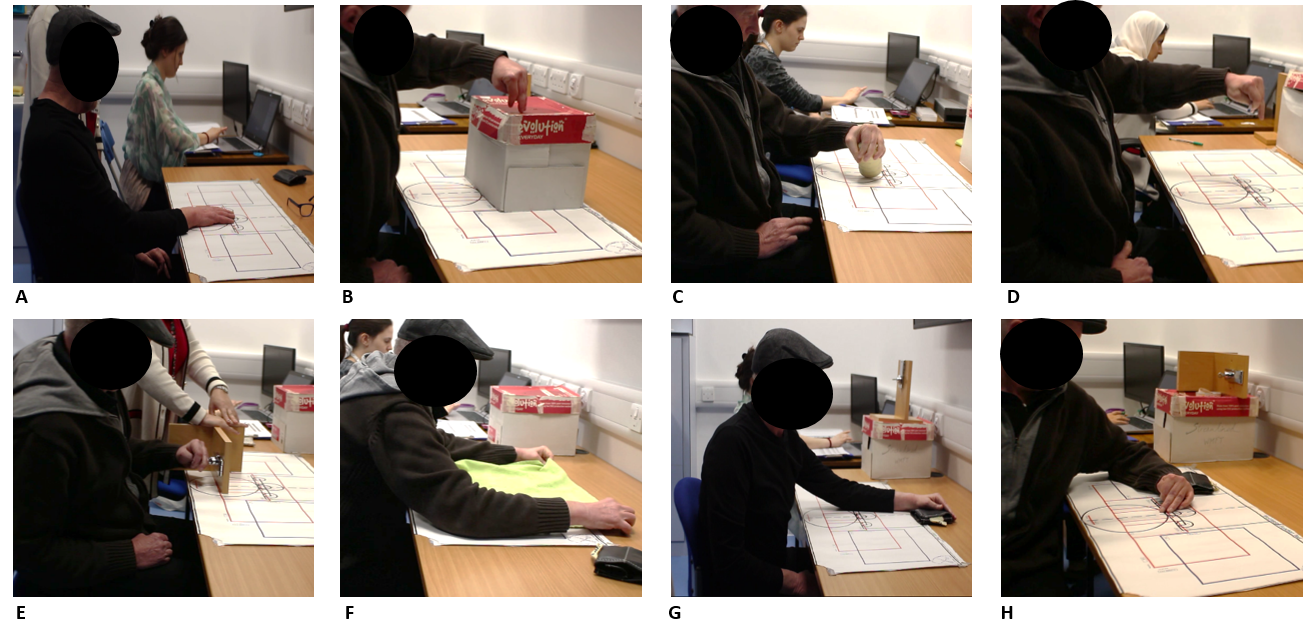


Figure 2: Stroke participant performing the eight tasks of SWMFT.

A: hand to table; B: hand to box; C: lift can; D: lift pencil; E: turn key in lock; F: folding towel; G: reach and retrieve; H: extend elbow (1lb weight)

**3) Trunk Range of Motion: Kinematic Analysis**

The kinematic analysis of the trunk ROM during the performance of SWMFT tasks was conducted using the Valedo® system. The Valedo® sensors contained a tri-axillar gyroscope, accelerometer and magnetometer, wireless antenna and signal processing unit. The specifications of the Valedo® system indicated that the measurement units were able to record ±0.1o ROM over a range of 360 o around all axes (Valedo® User Manual, Hocoma). The recorded data was transmitted to a laptop with a 200 Hz sampling frequency. The Valedo® system output files show the rotation of the sensors in the X, Y and Z directions on the three body planes (sagittal, frontal and transverse) over the duration of the task. Output files were exported in Excel file format. Initially the following parameters were exported for each task: flexion, axial rotation and lateral flexion on both sides for the sternal and sacral sensors. Following completion of the data collection, the data were analyzed to identify the most appropriate and important kinematic parameters to be reported in each task. The parameter of interest for each SWMFT task was determined according to clinical reasoning and discussion with the team. Table 2 shows the parameter of interest for each task with clinical reasoning supported by key literature.

Table : The parameters of interest for each SWMFT task (when the affected hand was tested)

|  |  |  |
| --- | --- | --- |
| SWMFT tasks - Parameter of interest | Clinical observation | Supporting literature |
| 1. Hand to table and 2. Hand to box  Trunk flexion  Trunk lateral flexion toward unaffected/dominant side  Trunk axial rotation toward affected/non-dominant side | 1 - The direction of the movement is forward.  2 - From video observation: lateral flexion movement toward unaffected side in combination with axial rotation of the affected side observed during reaching to the table and to the top of the table/box. | Significant trunk forward flexion and axial rotation shown during reaching forward while more trunk lateral flexion exerted during forward reaching in stroke subjects compared to healthy subjects from the sitting position (Messier et al., 2006). |
| 3. Lift can and 4. Lift pencil  Trunk flexion  Trunk lateral flexion toward unaffected/dominant side  Trunk axial rotation toward affected/non-dominant side | 1 - The direction of the movement is forward. So, participants move forward in order to reach the can/pencil.  2 - From video observation: stroke patients will need to do contralateral trunk flexion to be able to move their hand from their lap to reach the can/pencil in the middle of the table  3 - From video observation: trunk rotated toward affected side to take the can from table to mouth or to lift the pencil | “Stroke patients used considerably larger forward trunk displacements compared with controls” during reaching and drinking from a glass (Alt Murphy et al., 2011). |
| 5. Fold towel  Trunk flexion  Trunk lateral flexion toward unaffected/dominant side  Trunk lateral flexion toward affected/non-dominant side | 1 - The direction of the movement starts with forward flexion and the movement required to move laterally to both sides  2 - The task started with bilateral movement of the arms (to fold the towel lengthwise), followed by unilateral movement of tested arm (to fold the towel to the side). | Trunk muscle strength impaired bilaterally for both trunk flexors and extensors after stroke (Tanaka et al., 1998).    During bilateral movement a greater trunk flexion was used to do the task, while more trunk lateral flexion was exerted during unilateral movement (Messier et al., 2006). |
| 6. Turnkey in lock  Trunk flexion | 1 - From video observation: the key is in the middle of the table and very near to the participant (at the 8 cm. line). So, the stroke participants move forward to gain as much control as possible of the key. In addition, initial analysis of the data showed very small ROM for lateral flexion and axial rotation movements. |  |
| 7. Reach and retrieve  Trunk extension | 1 - The starting position of the task is shoulder flexion with arm extended on the table (hand at the 40 cm line). From video observation: no visible lateral flexion or trunk rotation happens during task performance; visible trunk extension is exerted to pull the weight until the thumb crosses the 8 cm line. In addition, initial analysis of the data showed a very small ROM for trunk lateral flexion and axial rotation. |  |
| 8. Extend elbow (1 lb weight)  Trunk flexion  Trunk lateral flexion toward affected/non-dominant side | 1 - The movement required is to push the weight away from the body using the affected side from a side sitting position. So, the direction of movement is laterally toward the side being tested.  2 - From video observation: some participants did the task with major trunk lateral flexion toward affected side. | Stroke survivors demonstrate significant trunk flexion during reaching to 45 degrees on both paretic and non-paretic sides compared to age-matched healthy controls (Messier et al., 2006). |

## Statistical Analysis

All the recorded data were processed using (MATLAB R2019). The MATLAB scripts for the data processing from raw data to ROM are detailed in (‎supplementary material). Data were exported into Excel files and analysed using IBM SPSS 24 (SPSS Inc, Chicago, IL). Descriptive statistics were used to describe the mean and SD of the data. The normality of the data tested using the Shapiro–Wilks test.

The validity of the Valedo system in measuring trunk ROM during the SWMFT was defined as the ability to distinguish between unimpaired (healthy) and impaired (stroke) groups, determined using two independent samples T-tests, and the ability to distinguish between the affected hand and the unaffected hand in the stroke group using a paired sample T-test.

The reliability of the Valedo® system in measuring trunk ROM during the SWMFT performance was determined using the ICC. Reliability was excellent when ICC >0.75, good to fair when ICC=0.4–0.74 and poor when ICC <0.4 (Fleiss, 2011). The ICC (2,1) model was used and 95% CIs were calculated for all ICC values. In addition,

standard error of measurement (SEM) and minimal detectable change (MDC) were calculated to estimate the possible variation from trial to trial resulting from repeating the test many times on a single subject.

## Results

### 1) Participant Characteristics

Twenty adults with chronic stroke with resulting UL impairment (mild to severe) and 20 age-matched healthy controls were recruited. The participants’ characteristics are presented in Table 3.

Table : Participant characteristics

|  |  |  |
| --- | --- | --- |
| **Characteristics** | **Chronic stroke**  **(n=20)** | **Healthy**  **(n=20)** |
| Age range (years)  Mean±SD | (48-82)  63.14±9.7 | (43-86)  66.9±11.1 |
| Gender  Male  Female | 13  7 | 10  10 |
| Hand dominance (before stroke)  Right  Left | 19  1 | 19  1 |
| Affected upper limb  Right  Left | 11  9 |  |
| Streamlined Wolf motor function test (SWMFT)  FAS (Mean±SD)  Time (Mean±SD) | 3.1±0.33  6.2±2.20 | 5±0  3.4±1.04 |

FAS: functional ability scale; SD: standard deviation

### 2) Validity

1. **Ability to Distinguish Between Impaired (Stroke) and Unimpaired (Healthy) Group**

It was possible to statistically significantly distinguish between impaired and unimpaired participants at a *p* level of <0.01 or less for all except four parameters of interest (trunk axial rotation (p=0.6) in task 2: hand to box; trunk flexion (p=0.83) and lumber lateral flexion toward non-dominant/affected side (p=0.35) in task 5: fold towel; and trunk flexion (p=0.18) in task 8: extend elbow) (Table 4).

1. Ability to Distinguish Between Affected and unaffected Hand Within Stroke Group

It was possible to determine a statistically significantly difference between the affected hand and the unaffected hand in stroke participants at a p level of <0.05 or less for most of the parameters of interest, indicating that the Valedo® system is valid to measure trunk ROM parameters during SWMFT performance (Table 5). Only five parameters showed a statistically non-significant difference between the affected hand and the unaffected hand (trunk axial rotation (p=0.56) in task 2: hand to box; trunk axial rotation (p=0.18) in task 3: lift can; trunk flexion (p=0.8) and lumber lateral flexion toward affected/unaffected side (p=0.17) in task 5: fold towel; and trunk flexion (p=0.06) in task 8: extend elbow).

Table : Differences between healthy (non-dominant hand) and stroke (affected hand) groups

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| SWMFT task | Parameter of interest | Healthy Mean ± SD | Stroke  Mean ± SD | Mean Diff ± SD | 95% CI for Mean Diff.  (lower-upper) | *P* value |
| Hand to table  (Front) | Trunk flexion | 1.38± 0.78 | 5.20±5.59 | 3.81±1.26 | 1.26–6.38 | 0.004\* |
| Trunk lateral flexion toward dominant/unaffected side | 3.20± 1.36 | 8.96±6.43 | 5.76±1.45 | 2.82–8.69 | 0.0003\* |
| Trunk axial rotation toward non-dominant/affected side | 4.08± 2.12 | 8.60±4.51 | 4.52±1.12 | 2.26–6.77 | 0.0002\* |
| Hand to box  (Front) | Trunk flexion | 4.85± 2.86 | 9.41±5.53 | 4.56±1.39 | 1.74–7.38 | 0.002\* |
| Trunk lateral flexion toward dominant/unaffected side | 5.08± 2.60 | 9.31±6.75 | 4.22±1.62 | 0.94–7.5 | 0.01\* |
| Trunk axial rotation toward non-dominant/affected side | 9.9± 4.07 | 9.16±4.63 | 0.73±1.37 | -3.5–2.05 | 0.6 |
| Lift can | Trunk flexion | 4.49± 2.56 | 12.61±6.72 | 8.12±1.61 | 4.79–11.43 | 0.00001\* |
| Trunk lateral flexion toward dominant/unaffected side | 3.19± 2.43 | 7.97±5.09 | 4.78±1.26 | 2.19–7.36 | 0.001\* |
| Trunk axial rotation toward non-dominant/affected side | 7.19± 3.11 | 10.13±5.65 | 2.93±1.44 | -0.02–5.88 | 0.003\* |
| Lift pencil | Trunk flexion | 3.64± 2.47 | 10.72±7.22 | 7.08±1.71 | 3.63–10.54 | 0.0001\* |
| Trunk lateral flexion toward dominant/unaffected side | 3.90± 1.91 | 8.96±6.10 | 5.06±1.43 | 2.16–7.95 | 0.001\* |
| Trunk axial rotation toward non-dominant/affected side | 5.77± 2.83 | 11±4.55 | 5.23±1.2 | 2.8–7.65 | 0.0001\* |
| Fold towel | Trunk flexion | 32.88± 6.65 | 33.39±8.39 | 0.51±2.39 | -4.34–5.35 | 0.83 |
| Lumber lateral flexion toward non-dominant/affected side | 2.21±1.97 | 9.29±10.25 | 7.07±3.16 | 2.34–11.79 | 0.004\* |
| Lumber lateral flexion toward dominant/unaffected side | 15.54±10.6 | 12.54±9.37 | 3±3.16 | -9.41–3.39 | 0.35 |
| Turn key in a lock | Trunk flexion | 1.47± 0.94 | 5.97±5.94 | 4.50±1.34 | 1.78–7.22 | 0.002\* |
| Reach and retrieve | Trunk extension | 6.06± 4.06 | 10.49±6.83 | -4.429±1.78 | -8.03 – -0.83 | 0.01\* |
| Extend elbow (side) | Trunk flexion | 2.72± 4.24 | 4.99±6.08 | 2.27±1.66 | -1.09–5.62 | 0.18 |
| Trunk lateral flexion | 0.69± 0.91 | 5.19±5.65 | 4.5±1.28 | 1.91–7.09 | 0.001\* |

\*p <0.05

Table : Differences between the affected hand and the unaffected hand in the stroke group (paired t-test)

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| SWMFT task | Parameter of interest | AF hand  Mean ± SD | Un-AF hand  Mean ± SD | Mean Diff ± SD | 95% CI for Mean Diff.  (lower-upper) | P value |
| Hand to table  (Front) | Trunk flexion | 5.20±5.59 | 1.02±1.88 | 4.18±1.27 | 1.50–6.85 | 0.004\* |
| Trunk lateral flexion toward affected/unaffected side | 8.96±6.43 | 3.58±2.04 | 5.38±1.34 | 2.57–8.19 | 0.001\* |
| Trunk axial rotation toward affected/unaffected side | 8.60±4.51 | 4.34±2.43 | 4.27±1.01 | 2.16–6.38 | 0.0004\* |
| Hand to box  (Front) | Trunk flexion | 9.41±5.53 | 5.15±3.68 | 4.27±1.48 | 1.61–6.92 | 0.003\* |
| Trunk lateral flexion toward affected/unaffected side | 9.31±6.75 | 5.99±2.79 | 3.32±1.56 | 0.05–6.59 | 0.04\* |
| Trunk axial rotation toward affected/unaffected side | 9.16±4.63 | 8.69±3.62 | 0.48±0.82 | -1.24–2.20 | 0.56 |
| Lift can | Trunk flexion | 12.61±6.72 | 5.32±2.88 | 7.29±1.64 | 3.65–10.93 | 0.0004\* |
| Trunk lateral flexion toward affected/unaffected side | 7.97±5.09 | 3.74±1.66 | 4.23±1.28 | 1.54–6.91 | 0.004\* |
| Trunk axial rotation toward affected/unaffected side | 10.13±5.65 | 8.31±3.17 | 1.81±1.30 | -0.92–4.54 | 0.18 |
| Lift pencil | Trunk flexion | 10.72±7.22 | 4.17±2.79 | 6.55±1.73 | 2.48±10.64 | 0.003\* |
| Trunk lateral flexion toward affected/unaffected side | 8.96±6.10 | 4.03±1.71 | 4.93±1.45 | 1.90–7.96 | 0.003\* |
| Trunk axial rotation toward affected/unaffected side | 11±4.55 | 6.75±2.62 | 4.25±1.02 | 2.11–6.39 | 0.001\* |
| Fold towel | Trunk flexion | 33.39±8.39 | 33.59±9.28 | -0.20±2.80 | -1.87–1.47 | 0.80 |
| Lumber lateral flexion toward affected/unaffected side | 9.29±10.25 | 10.44±9.39 | -1.16±0.82 | -2.88–0.57 | 0.17 |
| Lumber lateral flexion toward affected/unaffected side | 12.54±9.37 | 7.19±7.35 | 5.35±2.08 | 1–9.70 | 0.01\* |
| Turn key in a lock | Trunk flexion | 5.97±5.94 | 2.06±1.23 | 3.91±1.36 | 1.36–6.45 | 0.005\* |
| Reach and retrieve | Trunk extension | 10.49±6.83 | -6.35±3.51 | -4.14±1.72 | -7.26 – -1.02 | 0.01\* |
| Extend elbow (side) | Trunk flexion | 4.99±6.08 | 2.16±2.68 | 2.83±1.49 | -0.14–5.80 | 0.06 |
| Trunk lateral flexion | 5.19±5.65 | 1.61±2.80 | 3.58±1.22 | 1.02– .15 | 0.009\* |

\*p <0.05

### 3) Reliability

1. Intra-rater (Between Two Days Sessions)

Intra-rater reliability between days for measuring trunk ROM was very high in both the stroke and healthy groups. An excellent level of reliability with an ICC ≥ 0.75 was found as following: for the stroke group 14 parameters (74%) (trunk flexion in all tasks, trunk lateral flexion toward unaffected side in tasks 1, 2, 3, 4 and 8, trunk lateral flexion toward affected side in task 5 and trunk axial rotation toward affected/non-dominant side in task 2); for the healthy group in seven parameters (37%) (trunk flexion in tasks 3, 4 and 6, trunk lateral flexion toward dominant side in task 1, trunk lateral flexion toward non-dominant side in task 5 and trunk axial rotation toward non-dominant side in tasks 3 and 4). The remaining parameters for both groups showed good reliability with an ICC ≥0.64 (Fleiss, 2011). Similarly, the reliability coefficient in the stroke group was greater across parameters compared to the healthy group (Table 6). The MDC was relatively small across all parameters (MDC ≤ 8.2 in stroke and 5.6 in healthy), except for the trunk flexion parameter in task 5 (fold towel) (MDC in the stroke group= 13.3; MDC in healthy group=10.17) due to the large trunk ROM exerted in this task compared to the remaining seven tasks. The reliability coefficient in the stroke group was greater across parameters compared to the healthy group (Table 6). This could be due to a wider limit of agreement resulting from a high variation in task performance between participants in the stroke group.

1. Inter-rater (Between Two Raters)

Very similar results were demonstrated for the inter-rater reliability for trunk ROM parameters. The ICCs showed excellent reliability between assessors. An ICC ≥0.75 was found for the following: for the stroke group in 14 parameters (74%) (trunk flexion in tasks 1, 2, 3, 4 and 8, trunk lateral flexion toward unaffected side in tasks 1, 2, 3, 4 and 5, and trunk axial rotation toward affected/non-dominant side in tasks 1, 2, 3 and 4); for the healthy group in six parameters (32%) (trunk flexion in tasks 2 and 6, trunk lateral flexion toward dominant side in tasks 1 and 2, trunk lateral flexion toward non-dominant side in task 5 and trunk axial rotation toward non-dominant side in tasks 2 and 3) (Table 7). The remaining parameters for both groups showed good reliability with an ICC ≥0.63 (Fleiss 2011). The reliability in the stroke group was greater for the same reason mentioned previously. The SD difference between the two assessor measurements was high because the amount of ROM (degrees) exerted in each task was relatively low, and for some tasks (such as hand to table and hand to box) participants used 0 value (degree) trunk flexion, resulting in a higher SD. None of the CIs of any task included the value of zero, indicating statistically significant reliability.

Table 6: Intra-rater reliability for measuring trunk ROM during SWMFT performance (between two days)

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| SWMFT | Healthy (n=20) | | | | | | Stroke (n=20) | | | | | |
| Mean± SD | Mean diff.±SD | ICC 2,1 | 95% CI | SEM | MDC | Mean± SD | Mean diff.±SD | ICC 2,1 | 95% CI | SEM | MDC |
| 1. Hand to table  Trunk flexion  T1  T2  Trunk lateral flexion toward unaffected/dominant side  T1  T2  Trunk axial rotation toward affected/non-dominant side  T1  T2 | 1.2±0.8  1.4±0.8    3.1±1.3  3.2±1.7  4±2.2  4.1±2.1 | 0.2±0.6  0.1±0.9  0.06±1.6 | 0.7  0.82  0.71 | 0.37–0.86  0.61–0.92  0.40–0.87 | 0.32  0.38  0.86 | 0.88  1.05  2.38 | 4.8±6.1  5.3±5.8  8.1±6.6  8.2±7.4  9±4.5  9±6 | 0.2±4.2  0.3±4.2  1±3.6 | 0.8  0.86  0.71 | 0.55–0.91  0.66–0.94  0.39–0.87 | 1.87  1.57  1.93 | 5.18  4.35  5.34 |
| 2. Hand to box  Trunk flexion  T1  T2  Trunk lateral flexion toward unaffected/dominant side  T1  T2  Trunk axial rotation toward affected/non-dominant side  T1  T2 | 4.8±3.1  4.7±3.4  4.6±2.9  5.5±4.4  9.7±4.8  9.3±4.3 | 0.6±2.9  0.3±3.2  0.4±3.4 | 0.7  0.73  0.66 | 0.37–0.86  0.42–0.88  0.31–0.85 | 1.58  1.66  1.98 | 4.37  4.6  5.48 | 9.8±5.6  9.2±5.7    9.4±8  9.5±6.1  9.4±4.9  8.6±5.1 | 1±4.2  0.4±5.4  1.3±3.3 | 0.77  0.77  0.84 | 0.49–0.90  0.50–0.91  0.64–0.94 | 2.01  2.58  1.32 | 5.57  7.15  3.65 |
| 3. Lift can  Trunk flexion  T1  T2  Trunk lateral flexion toward unaffected/dominant side  T1  T2  Trunk axial rotation toward affected/non-dominant side  T1  T2 | 4.5±2.7  4.6±2.1  3.2±2.8  3.2±2.7    7.4±3.1  6.7±2.6 | 0.1±1.6  0±2.1  0.7±2.03 | 0.8  0.71  0.75 | 0.54–0.91  0.40–0.88  0.48–0.9 | 0.71  1.13  1.01 | 1.96  3.13  2.7 | 13.2±6.3  12±7.3  8.2±5.7  8.6±5.8  11±6.8  10.8±4.9 | 1.7±5.7  0.1±4.7  0.7±4.3 | 0.92  0.85  0.72 | 0.82–0.97  0.66–0.94  0.40–0.88 | 1.61  1.82  2.27 | 4.46  5.04  6.29 |
| 4. Lift pencil  Trunk flexion  T1  T2  Trunk lateral flexion toward unaffected/dominant side  T1  T2  Trunk axial rotation toward affected/non-dominant side  T1  T2 | 3.8±2.4  3.9±2.6    3.9±1.9  4.1±2.1  6±3.1  5.6±2.6 | 0.1±1.7  0.2±1.7  0.4±1.7 | 0.76  0.64  0.83 | 0.49–0.90  0.27–0.83  0.62–0.93 | 0.83  1.02  0.7 | 2.3  2.82  1.94 | 10.7±6.9  10.1±6.7  8.9±6.1  8.8±5.40  11.7±5.3  10.6±4.2 | 1.1±5.6  0.6±4.5  1.6±3.4 | 0.87  0.91  0.73 | 0.69–0.95  0.78–0.96  0.42–0.89 | 2.01  1.35  1.76 | 5.57  3.74  4.87 |
| 5. Fold towel  Trunk flexion  T1  T2  Trunk lateral flexion toward unaffected/dominant side  T1  T2  Trunk lateral flexion toward affected/non-dominant side  T1  T2 | 32.6±7.7  32.7±7.7  9.4±11.6  12.1±11  8.3±12.2  9.6±12.2 | 0.1±6.4  2.7±5.9  1.3±10 | 0.67  0.67  0.75 | 0.32–0.86  0.35–0.86  0.47–0.9 | 3.67  3.38  5 | 10.17  9.36  13.85 | 33.5±8.8  32.2±9.3  9.3±11.5  10±11.4  14.4±11.3  15.5±10.3 | 2.9±9.6  2±7.7  1±7.3 | 0.75  0.72  0.78 | 0.46–0.90  0.42–0.88  0.52–0.91 | 4.8  4.07  3.42 | 13.3  11.28  9.47 |
| 6. Turn key in lock  Trunk flexion  T1  T2 | 1.5±1.1  1.6±1.2 | 0.2±0.9 | 0.87 | 0.71–0.95 | 0.32 | 0.88 | 5.3±4.8  6.6±6.6 | 0.6±3.5 | 0.8 | 0.56–0.92 | 1.56 | 4.32 |
| 7. Reach and retrieve  Trunk extension  T1  T2 | 6.8±5.1  6.5±4.5 | 0.3±3.6 | 0.68 | 0.35–0.86 | 2.03 | 5.62 | 11.1±8.2  1.30±2 | 1.1±5.5 | 0.71 | 0.38–0.88 | 2.96 | 8.2 |
| 8. Extend elbow (1 lb weight)  Trunk flexion  T1  T2  Trunk lateral flexion toward unaffected/dominant side  T1  T2 | 2.5±4.6  1.9±4.2    0.7±1.1  1.1±2 | 0.6±2.2  0.2±1.3 | 0.73  0.68 | 0.43–0.88  0.36–0.86 | 1.14  0.73 | 3.15  2.02 | 5.6±7  3.90±5.6  4.9±5.5  3.1±5.7 | 1.9±4.2  2±3.5 | 0.77  0.8 | 0.49–0.90  0.52–0.92 | 2.01  1.56 | 5.57  4.32 |

SD: standard deviation; SEM: standard error of measurement; MDC: minimum detectable change; T1: first test at day 1; T2: re-test at day 2;

Cl: confidence interval

Table 7: Inter-rater reliability for measuring trunk ROM during SWMFT performance

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| SWMFT | Healthy (n=20) | | | | | | Stroke (n=20) | | | | | |
| Mean± SD | Mean diff.± SD | ICC 2,1 | 95% CI | SEM | Mean± SD | | Mean diff.± SD | ICC 2,1 | 95% CI | SEM |
| 1. Hand to table  Trunk flexion  T1  T2  Trunk lateral flexion toward unaffected/dominant side  T1  T2  Trunk axial rotation toward affected/non-dominant side  T1  T2 | 1.2±0.8  1.3±0.7    3.1±1.3  3.2±1.5  4±2.2  4±2.1 | 0.2±0.6  0.02±0.9  0.06±1.7 | 0.67  0.8  0.74 | 0.34–0.85  0.56–0.91  0.46–0.89 | 0.34  0.4  0.86 | 4.8±6.1  5.5±5.7  8.1±6.6  9±6.9  9±4.5  8.1±4.9 | | 0.6±2.8  0.9±4.4  0.6±2.3 | 0.9  0.83  0.86 | 0.75–0.95  0.62–0.93  0.67–0.94 | 0.88  1.81  0.86 |
| 2. Hand to box  Trunk flexion  T1  T2  Trunk lateral flexion toward unaffected/dominant side  T1  T2  Trunk axial rotation toward affected/non-dominant side  T1  T2 | 4.8±3.1  3.9±2.7  4.6±2.9  5.2±3.1  9.7±4.8  11.1±4.2 | 0.9±2.5  0.4±2.6  1.6±2.6 | 0.77  0.81  0.79 | 0.51–0.90  0.59–0.92  0.47–0.91 | 1.19  1.13  1.19 | 9.8±5.6  9.3±6    9.4±8  9.6±7.3  9.4±4.9  8.7±4.4 | | 0.4±2  0.2±5.4  0.7±3.3 | 0.94  0.77  0.75 | 0.86–0.98  0.47–0.90  0.48–0.89 | 0.48  2.58  1.65 |
| 3. Lift can  Trunk flexion  T1  T2  Trunk lateral flexion toward unaffected/dominant side  T1  T2  Trunk axial rotation toward affected/non-dominant side  T1  T2 | 4.5±2.7  3.8±2.5  2.8±2.5  3.3±2.8  7.4±3.1  7 ±3.7 | 0.7±2.1  0.1±2.1  0.4±2.3 | 0.73  0.7  0.77 | 0.43–0.88  0.37–0.86  0.51–0.90 | 1.09  1.15  1.11 | 13.2±6.3  11.9±6.8  8.2±5.7  7.1±4.9    11±6.8  9.9±5.4 | | 1.3±2.7  1.1±2.8  1.1±3.9 | 0.9  0.84  0.8 | 0.75–0.96  0.64–0.94  0.56–0.91 | 0.85  1.12  1.74 |
| 4. Lift pencil  Trunk flexion  T1  T2  Trunk lateral flexion toward unaffected/dominant side  T1  T2  Trunk axial rotation toward affected/non-dominant side  T1  T2 | 3.8±2.4  3.2±2.3  3.7±1.8  4.1±2.4    6±3.1  5.8±3.3 | 0.6±1.7  0.2±1.7  0.2±2.6 | 0.72  0.71  0.69 | 0.43–0.88  0.40–0.87  0.73–0.95 | 0.89  0.91  1.44 | 10.7±6.9  10.8±7.6  8.9±6.1  8.2±6.3  11.7±5.3  9.9±4.7 | | 0.05±2.4  0.7±4.2  1.8±2.5 | 0.95  0.78  0.83 | 0.87–0.98  0.52–0.90  0.46–0.94 | 0.53  1.96  1.03 |
| 5. Fold towel  Trunk flexion  T1  T2  Trunk lateral flexion toward unaffected/dominant side  T1  T2  Trunk lateral flexion toward affected/non-dominant side  T1  T2 | 32.6±7.7  32.2±8.1  9.40±11.6  10.8±11.2    8.3±12.2  6.8±9.3 | 0.4±6.1  1.4±8.4  1.5±5.9 | 0.71  0.74  0.75 | 0.40–0.88  0.45–0.9  0.47–0.89 | 3.28  4.28  2.95 | 33.5±8.8  34.1±8.9  9.3±11.5  9.3±9.4  14.4±11.3  10.7±8.8 | | 0.6±7.2  0.05±5.6  3.8±6.7 | 0.68  0.86  0.74 | 0.34–0.86  0.68–0.94  0.41–0.90 | 4.07  2.09  3.41 |
| 6. Turn key in lock  Trunk flexion  T1  T2 | 1.5±1.1  1.3±0.8 | 0.2±0.7 | 0.8 | 0.56–0.92 | 0.31 | 5.3±4.8  6.4±7.6 | | 0.4±2.9 | 0.63 | 0.28–0.84 | 1.76 |
| 7. Reach and retrieve  Trunk extension  T1  T2 | 6.8±5.1  5.7±3.9 | 1.1±3.4 | 0.73 | 0.45–0.88 | 1.76 | 11.1±8.2  10±6.5 | | 1.2±5.4 | 0.73 | 0.45–0.88 | 2.8 |
| 8. Extend elbow (1 lb weight)  Trunk flexion  T1  T2  Trunk lateral flexion toward unaffected/dominant side  T1  T2 | 2.5±4.6  2.8±4.1    0.7±1.1  0.4±0.7 | 0.3±2.9  0.3±0.8 | 0.71  0.64 | 0.41–0.87  0.28–0.84 | 1.56  0.48 | 5.6±7  5±7  4.9±5.5  5.5±6.9 | | 0.5±4.1  0.5±4.6 | 0.84  0.73 | 0.63–0.93  0.43–0.88 | 1.64  2.39 |

SD: standard deviation; SEM: standard error of measurement; MDC: minimum detectable change; T1: first test by assessor 1; T2: re-test by assessor 2;

Cl: confidence interval

## Discussion

The aim of this study was to establish the validity and reliability of using the Valedo system in measuring the quality of movement during performance of SWMFT. The results of this study showed that the Valedo system is a valid and reliable tool to measure trunk ROM parameters during the SWMFT performance in chronic stroke and age-matched healthy participants.

### 1) Validity

The validity of the Valedo® system in measuring trunk ROM during the SWMFT was measured by its ability to distinguish between impaired (stroke) and unimpaired (healthy) groups and between the affected hand and the unaffected hand within the stroke group.

As expected, the stroke participants employed more trunk movements than the healthy controls in all tasks. Furthermore, the stroke group showed a higher trunk ROM when performing the SWMFT tasks with the affected hand compared to the unaffected hand. This may be explained by the UL deficit (i.e. greater UL severity, more trunk compensatory movement used (Levin et al., 2016).

In terms of between-group differences, the results showed a statistically significant difference (*p*≤0.01) between healthy and stroke participants for all parameters except four (trunk axial rotation in task 2: hand to box; trunk flexion and lumber lateral flexion toward non-dominant/affected side in task 5: fold towel; and trunk flexion in task 8: extend elbow). Likewise, the same findings were seen within the stroke group when comparing the performance of SWMFT in the affected hand to the unaffected hand.. These findings indicate the Valedo® system’s high ability to distinguish between stroke and healthy as well as affected and unaffected hand performance through measuring trunk movement.

For task 2 (hand to box), the results of this study contradicted those of a previous study (Massie et al., 2012) that examined the contribution of trunk movement during reach between two targets 35 cm apart in a parasagittal plane at a height of 71 cm. That study found a significant difference (p<0.05) in trunk axial rotation between reaching with the affected side compared to reaching with the unaffected side. The disagreement between results could be due to the difference in the distance and the height of reaching. In this study, the box height was 11 cm and the box was located at the 20 cm line, which was lower and nearer to the participants, thus requiring less ROM to accomplish the task (Ma et al., 2017).

For task 5 (fold towel), the non-significant difference shown in both comparisons between groups in the trunk flexion and lumber lateral flexion toward non-dominant/affected side parameters could be explained by different factors. These include: 1) the towel measurements (W50 x L65 cm) mean the edge of the towel is placed on the table at 50 cm (generally beyond arm length), requiring forward high trunk flexion and lateral flexion movements for both groups to reach it; and 2) the functional level of the UL in the stroke group was low (FAS ≤2), and 35% (n=7) of the stroke participants used both hands (affected and unaffected) to accomplish the task, which could lead to an increase in the trunk ROM during task performance; these bilateral movements might affect the overall results. This explanation was confirmed by a previous study that measured the amount of trunk flexion and lateral flexion during unilateral and bilateral reaching tasks in chronic stroke patients (Messier et al. 2006). The results of that study showed greater trunk flexion and trunk lateral flexion were exerted during bilateral involvement of the UL compared to unilateral movement in the stroke group.

For task 8, the non-significant difference in trunk flexion, either when comparing healthy participants to stroke participants or affected hands to unaffected hands, might be due to the nature and direction of the task. In this task, the participants sit at the side of a table (side of chair attached to the side of table) with the arm resting on the table (parallel to front edge of the table with the elbow at the 14 cm line) and are asked to extend the elbow until the thumb crosses the 40 cm line. Thus, the direction of the movement is toward the side being tested, and the weight needs to be pushed toward the lateral/backward direction while the trunk is supported by the back of the chair. As a result, it would be unexpected to perform forward trunk flexion to accomplish task 8.

In addition to the previous three tasks discussed, the trunk flexion in task 3 (lift can: participant is required to move the tested hand from the lap and grasp the can placed just beyond the 20 cm line and then move it toward the mouth) showed a non-significant (p=0.8) difference between the affected hand compared to the unaffected hand within the stroke group. This finding is expected in the stroke group, as it has been reported in previous literature that trunk muscle strength is impaired bilaterally for both trunk flexors and extensors, which might affect the performance of participants in this task (Jung et al., 2020, Tanaka et al., 1998). Furthermore, 45% (n=9) of the stroke participants used both hands to accomplish that task due to the low functional level of their UL (FAS ≤2), which might have affected the overall results for that task. This explanation is supported by Alt Murphy (2011), who found that stroke patients with a moderately affected arm used considerably larger forward trunk displacements (p<0.05) during the reaching and drinking task performed from the sitting position compared with stroke patients who had a mildly affected arm.

### 2) Reliability

In the current study, the inter-rater and intra-rater reliability showed good to excellent reliability in both groups, as follows: intra-rater reliability (between 2 days) in healthy participants (0.64–0.87) and stroke participants (0.71–0.92); and inter-rater reliability (between two raters) in healthy participants (0.64–0.81) and stroke participants (0.63–0.95). All types of reliability were better for the stroke group than for the healthy group. A possible explanation for this finding is that the variation in trunk ROM between subjects was limited in the healthy group compared to the stroke group, which led to a restricted spread of scores. Moreover, the participants in the healthy group had the highest FAS score (FAS average=5) for the UL, while the participants in the stroke group varied in their UL ability (average FAS=3.1, and the FAS in each task varied from 0–5), which makes the stroke group non-homogenous and leads to an increase in the reliability level. This explanation has been confirmed by Portney and Watkins, who state ‘the variability among subjects’ scores must be large to demonstrate reliability. A lack of variability can occur when samples are homogeneous, when raters are all very lenient or strict in their scoring, or when the rating system falls within a restricted range’ (2013; p. 607).

Another possible explanation for the higher reliability in the stroke group is the instructions used in this study to perform the required tasks. The SWMFT instructions were used, which focus on doing each task as quickly as possible without encouraging non-use of the trunk, because we wanted to explore how healthy and stroke participants move their trunk during UL activities. However, some (n=2–5) of the healthy participants moved their trunk further than the other healthy participants in trunk flexion in tasks 5 and 8, which could have affected the reliability level. Another possible reason for the good reliability in task 7 in both groups is that the standardisation of the starting position in that task is quite challenging because the starting position requires the tested arm to be extended and the palm of the hand to be in contact with the weight (placed beyond the 40 cm line); sometimes, it is not possible to fully extend the arm for stroke participants (n= 6) who have spasticity. In addition, healthy participants who have a short arm length are in full contact with the table (n=4), which could have affected their performance.

The last factor that could affect the reliability is the variability in sensor placement between each assessment and between the two raters, as it has been found to be a factor that affected inter-rater reliability in a study assessing the reliability of inertial measurement systems when measuring seated spinal postures (Schless et al. 2015). This factor was mitigated by using bony landmarks to identify S1 and L1 levels as mentioned in the measurement protocol to ensure the same placement of the sensors by assessors.

In summary, the Valedo® system can be considered as providing a valid and reliable measure of trunk movement during the SWMFT performance and is able to detect small changes in trunk ROM that may not be observed clinically. These findings suggest that clinician and researchers could consider using the Valedo® system as a valid and reliable tool to detect trunk compensatory movements during UL tasks, which could be useful when designing rehabilitation programmes for people with chronic stroke.

## Limitations of the Study

This study has several limitations. The inclusion criteria for the UL ability of stroke participants resulted in the inclusion of a wide variation of UL abilities (FAS 0-5), which could have affected the generalizability of the results. Human error in palpation when replacing the sensors on the trunk might also have affected the reliability in both groups.

The sample size was enough to examine reliability (n=20 stroke) but too small to allow definitive conclusions to be drawn about differences in parameters between stroke participants (stroke participants who scored 0, 1, 2, 3, 4 and 5 in the clinical SWMFT) and to do subgroup analysis for each FAS.

## Conclusion and Clinical Implications

Good to excellent inter-rater and intra-rater reliability was found for the trunk ROM parameter measured during SWMFT, suggesting an acceptable level of reliability for the Valedo® system to be used to measure trunk ROM in healthy and stroke participants. The Valedo® system gives more information about trunk performance during SWMFT, with the ability to detect small changes in trunk ROM that may not be observed clinically. These findings indicate that the Valedo® system has important potential for the objective assessment of trunk ROM during UL activity in clinical practice to address trunk control issues. Another potential use of the Valedo® system is in future research to better understand compensatory trunk movements during UL activities. The potential research and clinical applications of the Valedo® system extend to the wider neurological community. Further studies with a larger sample size, different level of UL impairment and different stroke stages are warranted to establish reference data for trunk ROM parameters using different FAS in the stroke population.

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